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JULY, 1931

DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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BISMUTH

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

BISMUTH[1]

By Paul M. Tyler[2]

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INTRODUCTION

Bismuth is a useful metal and rather an uncommon one. The element probably constitutes much less than one-millionth part of the earth's crust, but the potential supply - to no small extent as a by-product of the production of lead and copper with which it is associated in nature - has tended for many decades to exceed the demand. A single mine in Bolivia could readily flood the world's markets, and considerable quantities of bismuth are allowed to escape recovery at many smelting plants.

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[1] The Bureau of Mines will welcome reprinting of this article, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6466."

[2] Chief engineer, rare metals and nonmetals division, U. S. Bureau of Mines.

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In short, bismuth is an element that, although not actually unemployed, seems able to perform a larger share of the world's work than it does. Attempts to enlarge the demand by the simple expedient of lowering the price have failed, and producers have hitherto deemed it wiser to market a smaller quantity at a remunerative price rather than to hazard their present fairly safe profits against the doubtful prospect that new consumers would voluntarily appear to take sufficiently larger quantities at lower prices. Renewed efforts are being made to enlarge demand and to make use of some of the unique properties of the metal. The situation constitutes a nice problem in the theory of marketing, and is of interest to the economist as well as to producers and consumers of metals.

DESCRIPTION AND PROPERTIES[3]

Bismuth is a soft, heavy, coarsely crystalline, brittle metal. The color is tin white with a distinctly reddish tinge. It is one of the few substances that expand on cooling. The density at 20° C. is 9.80 and 10.067 at the melting point. When it solidifies from the molten condition, it expands to the extent of 3.32 per cent of the solid volume at the melting point. The density of molten metal decreases, however, as it is heated, from 10.062 grams per cubic centimeter at 275° C. to 9.611 at 650° C. The hardness is a little over 2 on the Moh scale and 7.3 on the Brinell scale, decreasing rapidly with increase in temperature even slightly above normal and far below the melting point. At atmospheric pressure, pure bismuth melts at 271° C. and vaporizes at 1,440 to 1,500° C. As in the case of water, increases in pressure substantially lower the melting point and raise the boiling point.

The thermal conductivity of bismuth is less than that of any other metal except mercury, and it is an even poorer conductor of electricity than that metal. For most metals the electrical resistance is roughly doubled when they are melted; with bismuth it is the reverse, the molten metal being more than twice as good a conductor as the solid. Antimony is the only other metal whose resistance decreases when melted, and the difference in that case is far less marked.

The thermoelectric properties of bismuth are remarkable. The pure metal possesses a thermal e.m.f. of about 80 microvolts per degree Centigrade against silver. A junction between pure bismuth and a bismuth alloy containing 5 to 6 per cent tin may develop an e.m.f. of about 120 microvolts per degree and a bismuth-tin alloy coupled with copper may yield a difference in electrical potential of 376 microvolts per degree rise in temperature.

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[3] Numerical data taken from U. S. Bureau of Standards Circular No. 382, Bismuth, April 2, 1930.

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In its magnetic properties bismuth is also an unusual metal. It is the most diamagnetic of all metals; instead of being attracted like iron to a magnet, it is strongly repelled by either pole. This property is less at higher temperatures. An alloy of bismuth with copper and manganese (which are likewise diamagnetic, though to a much less degree) is distinctly magnetic. When bismuth is placed in a magnetic field it becomes a better conductor of both heat and electricity.

In the periodic chart of the atoms, bismuth is element number 83, coming next to lead, which is element number 84. It is also in the same vertical column with antimony. The atomic weight (209.00) is higher than that of any other known element except the radioactive elements. As might be expected from its position in the periodic table, bismuth greatly resembles both lead and antimony in its physical and chemical properties. The absorptive powers of bismuth for X-rays are similar to those of lead. In its chemical reactions, it more nearly resembles antimony. In practically all of its compounds, however, bismuth is trivalent and perhaps the most characteristic property of the salts is the ease with which they hydrolyze in dilute solution, forming insoluble basic salts.

USES

Bismuth, since it is even more crystalline than antimony or arsenic is much too brittle to be used alone. Its alloys are used for sprinkler plugs and other fire protective devices, electrical fuses, low melting solders, dental amalgams, and tempering baths for small tools. In most of these alloys the function of the bismuth is to lower the melting point and certain of them, such as Wood's, Rose's, Darcet's, Guthrie's, Newton's, Onion's, and Lipowitz's metal (all of which contain 47 per cent or more of bismuth) melt when placed in hot water. Some of these alloys are used for making casts of insects and other fragile objects. Wood's metal has been used to join the ends of quartz rods and tubes. The quartz is platinized, plated, and tinned and then inserted into special tinned sockets and the joint made with Wood's metal. A patent[4] has been issued for an antimonial-lead alloy with 2 to 16 per cent bismuth and a little cadmium to be used in bonding glass. Bismuth improves the casting properties of tin and lead by lowering the surface tension, thereby producing sharply defined castings even when the percentage of bismuth (or antimony) is insufficient to cause the metal to expand and fill the mould at the moment of solidification. Bismuth also acts as a hardening agent, and its use has been recommended for this purpose in lead plates for storage batteries.

By far the major use of bismuth, however, has been in the form of its compounds which are extensively used in medicinal and cosmetic preparations, including various indigestion remedies and toilet powders. A number of the compounds are used in treating wounds and the metal is therefore of some importance in time of war. Insoluble salts of bismuth are given to patients preparatory to X-ray examination of the digestive tract. Minor amounts of bismuth compounds have been used in porcelain painting, in enameling, and in optical glass manufacture.

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[4] Geppert, J., Lead alloy for bonding glass, United States patent 1,584,927, May 18, 1926.

The Bureau of Standards has recently been engaged in research with the view of extending the uses of bismuth, endeavoring not so much to substitute it for other metals now in use but seeking to utilize the unique properties of the metal itself. In the course of this work bismuth wire, in lengths of 20 feet, has been produced successfully for the first time by extrusion. Dr. J. G. Thompson, research associate for the Cerro de Pasco Copper Corporation has outlined some of the less well-known and potential uses of the element as follows:[5]

> Some of these alloys have been used for making delicate castings, such as dental dies from plaster impressions; to hold delicate castings or pieces of irregular shape during machining or testing operations; to furnish gas-tight liquid seals for apparatus, such as nitriding ovens; and for toys, such as the "magic teaspoons" which melt in hot water. Bismuth amalgams, with or without lead and tin, have been used for the production of mirrors whose luster is reported equal to that of silver.
>
> Bismuth added to tin will impart hardness, sonorousness, luster, and fusibility. A 10 per cent addition of bismuth improves the appearance of a tinned joint on hot or cold rolled steel. An alloy for hardening bearing metals contains Sb 70 parts by weight, Sn 25, Cu 3, Bi 2. Bismuth has been used in Britannia metal and pewter. From their relative positions in the electrochemical series, the addition of bismuth up to the limit of its solid solubility in either tin or lead should improve the resistance to oxidation of these metals.
>
> Bismuth alloys - for example, those with lead - whether high or low in bismuth, have good casting qualities and produce good impressions of the mold. For this reason, pure bismuth or Birich alloys have been used in making patterns, and smaller amounts of bismuth (up to 15 or 20 per cent) have been used in stereotype and similar metals. The pure metal and the very rich alloys expand on solidification, but the alloys of lower bismuth content contract. They produce sharply defined castings in spite of this contraction because the presence of bismuth, or of antimony, in the case of lead-antimony alloys, lowers the surface tension and the viscosity of the molten mixture, so that, while still liquid, it follows the contours of the mold.
>
> Bismuth, in amounts up to about 1 per cent, has been added to various brasses and bronzes and to antifriction metals, but smaller amounts of bismuth, or when it is present as an impurity, are usually regarded with extreme suspicion. Small amounts present in copper or gold make them unworkable, and the presence of bismuth in lead which is intended for the manufacture of white lead is objectionable, as it leads to an off-color product.

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[5] U. S. Bureau of Standards, Work cited, pp. 8-9.

Bismuth wire, prepared either by extrusion at elevated temperatures or by melting and drawing within glass tubes has been used in thermocouples, pyrometers, galvanometer suspensions, hair lines for microscopes, etc. The high thermal e.m.f. of bismuth can be used to produce a very sensitive thermocouple, but the wire is brittle and difficult to handle. If the wire is prepared by drawing down a glass tube filled with metal, the glass may be removed with hydrofluoric acid or left for insulation and protection.

The electrical and thermal conductivities of bismuth are extraordinarily low and the electrical conductivity further decreases when exposed to the influence of a magnetic field. Consequently, bismuth has been used in the construction of instruments for determining the strength of magnetic fields.

It has been reported that bismuth up to 2 per cent, like silicon, increases the electric resistance of steel without diminution of the magnetic permeability or dissipation of energy through hysteresis. Bismuth steels have been suggested as a substitute for silicon steels for transformer sheet. From a study of the iron-bismuth diagram it is difficult to understand how bismuth steels can be made.

Miscellaneous uses for bismuth include the following items: Metallic pencils have been made of an alloy consisting of 90 parts by weight of bismuth, 70 lead, and 8 mercury; in the separation of the metals of the platinum group, fusion with bismuth has been employed to dissolve rhodium; plates of metallic bismuth have been used as a surface for friction and lubrication tests, as these plates are more easily cleaned of grease than is glass.

Bismuth compounds have found some uses outside of pharmaceutical and medicinal preparations. Organo-metallic compounds of bismuth possess decided "antiknock" properties, although they are only about one-third as efficient as lead compounds in this respect. Bismuth trichloride is claimed to render less inflammable some waterproofing materials, such as tar, creosote, and nondrying oils. Bismuth trioxide has had some small use as a pigment and in vitreous enamels, porcelain, and glass, chiefly as a flux to increase the fusibility of coloring oxides or compounds. In these uses it resembles lead oxide, but has the advantage of being nonpoisonous. A mixture of the composition Bi_2O_3:3Zn has been patented as a catalyst in the synthesis of methanol. Catalysts for the oxidation of ammonia have been made by adding bismuth oxide to iron oxide. Bismuth trioxide has been used as a catalyst for the oxidation of hydrocyanic acid. Owing to the volatility of Bi_2O_3, the life of some of these catalysts at high temperatures is short.

HISTORY[6]

Bismuth seems to have been known in the Middle Ages, but its identity was confused with that of lead and tin and also with antimony. Toward the end of the sixteenth century, G. Agricola referred to bisemutum or plumbum cinereum as a specific metal different from lead and tin; about 100 years later, however, M. Ettmuller considered that bismuth and tin were merely different kinds of lead. He added that bismuth approaches more nearly to silver, a theory which Agricola had noted, bismuth then being also called testum argenti since it was supposed to be silver which nature had not yet perfected. Even in the early part of the eighteenth century, however, the nature of bismuth was still in doubt, as indicated by the following deductions made by N. Lemerg:

> Bismuth is a sulphureous marcasite found in tin mines. Many believe that bismuth is imperfect tin which partakes of a good store of arsenic. ***It is more probably a regulus of tin prepared artificially in England in imitation of a rare natural bismuth. ***The pores of bismuth are disposed in another manner than those of tin because the menstruum which dissolves tin cannot entirely dissolve bismuth.

J. Hellot, on the other hand, was inclined to think that bismuth was a specific metal and he made a button of what he considered true bismuth from a cobaltiferous bismuth ore. In 1739, J. H. Pott observed the action of many chemicals upon bismuth and in 1753, C. J. Geoffroy showed that bismuth is a distinct element, though it has many analogies with lead.

It is not unlikely that the word bismuth was a corruption of the German wis mat, a German miner's term for a white mass (cf. weisse masse) or a white metal. An effort has been made, however, to connect it with the Arabian wiss majaht, because it melts as readily as a certain gum.

OCCURRENCE

Bismuth is rather an uncommon element. Clarke and Washington[7] estimate that it represents less than one-millionth part of the earth's crust and Vogt[8] places the ratio at less than one part in 10 million. Bismuth frequently occurs native and the metal and the sulphide, bismuthinite (Bi_2S_3), are its chief ore minerals. Two silicates, several sulphosalts, and the telluride, oxide, carbonate, molybdate, vanadate, and arsenate exist as relatively rare mineral species.[9] Bismuth ochre or bismite ($Bi_2O_3 \cdot 3H_2O$) is the commonest oxidation product in deposits.

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[6] Mainly from Mellor, J. W., A comprehensive treatise on inorganic and theoretical chemistry: London, vol. 9, 1929, pp. 587-8.

[7] Clarke, F. W. and Washington, H. S., The composition of the earth's crust. Proc. Nat. Acad. Sciences, vol. 8, 1922, p. 108.

[8] Vogt, J. H. L., Ztschr. prakt. Geol., vol. 7, 1899, pp. 10, 274.

[9] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey, Bull. 770, 5th ed., 1924, p. 14.

Bismuth minerals occur in veins in gneiss and other igneous rocks and also in sedimentary rocks, notably shales. They rarely occur except associated with other ores. Mellor[10] groups bismuth deposits in three classes: (1) Bismuth-tin deposits in which the bismuth is associated with tin and copper, with tungsten and molybdenum as accessories - e.g., the Bolivian deposits, and those of Chile, Peru, Argentina, Queensland, New South Wales, Tasmania, France, and Cornwall. (2) The bismuth-cobalt deposits in which the bismuth accompanies cobalt and uranium - e.g., the deposits in Saxony. (3) The bismuth-gold deposits - e.g., those in Queensland, New South Wales, Norway, and the United States. Bismuth occurs as an accessory constituent of many ores and minerals, especially in copper minerals.

EXTRACTION OF BISMUTH

Bismuth ores after a preliminary concentration by hand-sorting or gravity methods may be further treated either by wet or by dry methods. The wet methods are usually based on the fact that bismuth may be hydrolized from chloride solutions. Liquation processes were in use at one time in Saxony but, being quite wasteful, were superseded by smelting. Because of the easy volatility of bismuth and its oxide, smelting has to be conducted at a rather low temperature.

Detailed outlines of various smelting and refining processes for bismuth are given by Hayward.[11] Carbon or iron may be used as the reducing agent and soda ash and sometimes fluorspar have to be added to produce slags that will be liquid at low temperature. In cupelling bismuth-bearing lead the bismuth is removed mostly in the litharge that forms toward the end of the operation. Such litharge which contains about 20 per cent bismuth is dissolved in hydrochloric acid and the bismuth recovered from the filtered solution by diluting and neutralizing most of the free acid with milk of lime or soda ash. The bismuth oxychloride from this source is heated with lime or soda ash to fix the chlorine and is then smelted. Slimes from the Betts' electrolytic lead refining process, virtually the sole source of bismuth produced in the United States, are fused with caustic soda and soda ash (also sodium sulphate if copper is present) and the metal is cast into slabs for electrolytic refining. Another method for treating slimes is to (1) subject them to an oxidizing fusion similar to cupelling, (2) treat the bismuth product from the first fusion in a second furnace, and (3) reduce the slag from the second furnace with salt cake and carbon producing an impure bismuth metal which is (4) cast into anodes and refined electrolytically.

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[10] Mellor, J. W., Work cited, p. 589.

[11] Hayward, C. R., Outline of Metallurgical Practice: New York, 1929, p. 324-331.

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Since the principal use of bismuth is in medicinal and pharmaceutical preparations the product must be of high purity (99.9 per cent bismuth and free from arsenic). Refining, therefore, is the most difficult part of the operation and always involves an intricate series of treatments for the removal of contaminating elements. Formerly all of the bismuth for the pharmaceutical trade was refined by wet methods, but material refined entirely by dry processes is now on the market.[12]

The preparation of the more important salts of bismuth used in medicine and pharmacy is described in the footnote references.[13]

WORLD PRODUCTION

The world output of bismuth is from 400 to 500 tons annually. The available statistics of several countries are either lacking or presented in terms of ore or concentrates for which the percentage content is not given but the average probably lies within the figures stated. Roughly one-half the total is derived from Bolivian ore, most of which is refined in England. The United States, Germany, and Spain are the other principal sources of supply, probably about in the order named. Australia, formerly a major producer, has gradually become of minor importance. Peru is an occasional contributor and is a prospective source of by-product production on a considerable scale. China, Japan, British Africa, and parts of the former Austria-Hungarian Empire also may be mentioned.

Available figures for the various countries are assembled in the accompanying tables.

DOMESTIC PRODUCTION

Practically all the bismuth produced in the United States has been obtained from the treatment of slimes resulting from the refining of lead bullion by the Betts' electrolytic process. For a few years bismuth was recovered from electrolytic tin refinery slimes but the last of these plants ceased operations in 1924. Ores containing a considerable percentage of bismuth are not common in this country but lead ores and copper ores carrying small amounts of bismuth are mined, especially in Utah (Tintic, Little Cottonwood, Clifton, and Beaver Counties) and also in Nevada (Hilltop, Eureka, Luning, and Pioche districts), Colorado (Lake and Summit Counties), New Mexico (Eagle), and Arizona (Yuma County). Lead produced from these ores is refined mostly in the Betts' process plants at Omaha, Neb., or East Chicago, Ill. Flue dust at many plants also constitutes a potential source of supply. At Murray, Utah, an analysis of the dust from the lead blast furnaces showed about 0.5 per cent Bi, 35 per cent As, 40 per cent Pb, 15 per cent Cd, 0.7 per cent Sb, and 0.5 per cent Se. Mexican lead bullion also may contain considerable bismuth.

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[12] U. S. Bureau of Standards. Work cited, p. 4.

[13] Chemnitius, F., Manufacture of bismuth salts: Pharm. Zentralb., vol. 68, 1927, pp. 513-518.
Mauersberger, E. A., Manufacture of bismuth salts: Chem. Werkblad., vol. 27, 1930, pp. 337-8.

World's production of bismuth metal, 1900-1929[a]

(Metric tons)

Countries	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Australia:																														
New South Wales	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Northern Territory	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	p	d	p	d	d	d	d	d	d	d	d	d
Queensland	q8	q20	q1	q11	q21	15	7	q6	q23	10	21	10	6	2	1	3	4	4	1	2	1	e	2	—	—	1	—	—	d	d
Tasmania	—	—	—	—	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	d	d	d	d	d	d	d	d
Western Australia	d	d	d	d	d	d	d	d	d	d	d	d	d	—	p	p	p	p	—	p	—	—	d	d	d	d	d	d	d	d
Austria	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	p	p	d	d	d	d	d	—	p	d	d	d	d	d	d
Bolivia	d	d	d	d	d	d	d	d	p	p	p	p	p	p	p	p	p	255	249	169	195	—	m138	m210	m170	p	p	p	p	112
British India	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	e	—	—	—	—	d	d	d	d	d	d	d	d
Germany (Saxony)	d	d	d	d	d	d	d	d	d	d	d	d	d	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	d
Japan	—	—	—	p	—	—	—	—	p	p	—	—	—	o	o	o	o	o	1	e	e	1	3	7	30	27	26	23	32	i
Norway	—	—	—	—	—	—	—	—	p	—	—	—	—	—	—	p	—	p	p	—	—	—	—	—	—	—	—	d	d	d
Peru (exports)	d	d	d	d	d	12	—	13	9	30	24	24	51	25	11	—	—	1	—	—	8	d	6	1		d	d	d	d	d
Rhodesia (Northern)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	p	—	p	—	p	—	—	—	-	—	3	d	d	d
Spain	—	—	—	—	—	—	—	—	p	p	p	p	p	p	p	p	p	p	12	20	25	22	9	22	41	37	26	21	24	d
Union of South Africa	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	—	—	p	—	—	d	d	d	d	d	d	d	d
United States	—	—	—	—	—	—	—	—	—	—	—	—	—	84	—	—	—	—	—	145	114	147	—	186	136	136	136	r	r	d
China	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	—	—	p	p	p	p	—	p	p	p	d	d	d
Canada	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	—	—	—	—	—	d	d	6	8	3	1	6	85
Total[n]	8	20	1	11	21	27	7	19	32	40	45	34	57	111	12	3	4	260	263	336	343	170	158	426	383	209	194	45	62	197

a Data mainly from the Mineral Resources, 1922, of the United States Geological Survey, New South Wales Department of Mines Annual Report, Queensland Annual Report of the Acting Under-Secretary of Mines, Tasmania Annual Report of the Secretary of Mines, and The Mineral Industry of the British Empire and Foreign Countries.

b In addition to the countries listed, Argentina reports rail shipments as follows: 1916, 18,800 kilograms; 1917, 275,660 kilograms; 1918, 28,000 kilograms; a large part and probably all of this ore, however, is Bolivian. Hungary reports for 1917 a production of 7,158 quintals (715,800 kilograms) of ore; and from Madagascar 126 kilograms of bismuth was exported during 1913. c Ore and metal combined; figures not shown separately. d No data available. e Less than 1 ton. f Metal reported.

g Czechoslovakia; year ended September 30. h Exports. i Ore and concentrates. j Content of ore and concentrates. k Includes bismuth-cobalt-nickel ore.

l Included with bismuth ore. m Year ended September 30. n Does not include bismuth produced in countries for which production statistics are not available.

o Ore and metal combined reported under ore. p Ore reported. q Includes bismuth and wolfram. r Figures not available for publication.

World's production of bismuth ore, 1900-1929 (a)

(Metric tons)

Countries (b)	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Australia:																														
New South Wales (c)	11	21	10	22	40	55	25	16	9	9	6	8	6	9	15	18	30	20	31	19	77	8	5	6	15	11	8	1	7	3
Northern Territory	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	e	d	e	—	d	d	d	d	d	d	d	d
Queensland (bismuth and wolfram concentrates)	f	f	f	f	f	22	23	f	f	64	34	129	192	185	196	251	139	133	116	142	50	—	—	—	1	—	—	6	—	—
Tasmania	—	—	—	—	e	4	e	e	4	3	11	14	8	5	6	6	4	4	4	2	e	e	d	d	d	d	d	d	d	d
Western Australia (exports)	d	d	d	d	d	d	d	d	d	d	d	d	d	d	9	1	e	1	—	e	—	—	d	d	d	d	d	d	d	d
Austria	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	602	325	d	d	d	d	d	d	g119	d	d	d	d	d	d
Bolivia: (h)																														
Concentrates	d	d	d	d	d	d	d	d	160	237	311	415	478	422	438	475	447	58	76	38	27	5	115	i	i	j	j	j	j	3
Ores	d	d	d	d	d	d	d	d	d	d	d	d	d	—	112	182	168	121	112	94	153	24	11	i373	i399	j337	j223	j109	j136	25
Residues	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	6	54	100	54	73	63	—	40	d	d	d	d	d	d	10
British India	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	f	—	—	—	—	—	—	e	—	—	e	e	d
Germany (Saxony):																														
Bismuth ores	d	d	d	d	d	d	d	d	d	d	d	d	d	51	58	46	374	49	113	66	31	27	k127	5	5	7	8	5	5	d
Bismuth-cobalt-nickel ores	d	d	d	d	d	d	d	d	d	d	d	d	d	166	161	151	118	133	156	122	121	124	L	—	—	—	—	—	—	—
Tin-bismuth ores	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	—	31	9	1	e	—	—	—	—	—	—	—	—
Japan	—	—	—	e	—	—	—	—	e	e	—	—	—	e	c4	c10	c1	c2	1	e	f	f	f	f	f	f	f	f	f	d
Norway	—	—	—	—	—	—	—	—	12	—	—	—	—	—	—	10	—	10	1	—	—	—	—	—	—	—	—	d	d	d
Peru (exports)	d	d	d	d	d	f	—	f	f	f	f	f	f	f	f	—	—	f	—	—	f	d	f	f	d	d	d	d	d	d
Rhodesia (Northern)	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	e	—	1	—	1	—	—	—	—	—	f	d	d	d
Spain	—	—	—	—	—	—	—	—	96	78	53	52	73	56	40	16	11	14	34	75	53	54	49	91	125	145	97	96	129	d
Union of South Africa	d	d	d	d	d	d	d	d	d	d	d	d	d	—	—	—	—	—	—	e	—	—	d	d	d	d	d	d	d	d
United States	—	—	—	—	2	11	3	—	—	—	—	—	—	f	—	—	—	—	—	f	f	f	—	f	f	f	f	d	d	d
China	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	h54	h91	h121	h56	d	m78	m60	m35	d	d	d
Canada	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d	f	f	f	f	f	f
Total (n)	11	21	10	22	42	92	51	16	281	391	415	618	757	894	1039	1774	1671	645	730	694	678	373	403	594	623	560	371	217	277	41

(See table on "World's production of bismuth metal" for footnotes.)

The United States Smelting, Refining, and Mining Co. was the first commercial producer of bismuth in the United States and has continued to produce the metal since 1906. The other principal producer is the American Smelting and Refining Co. Since in most years there have been only two producers, and never more than four, the Bureau of Mines has not been at liberty to publish production figures. It is common report, however, that the domestic output has generally ranged from 250,000 to 350,000 pounds annually.

IMPORTS

Prior to 1906, the entire supply of bismuth was obtained from Europe, imports of the metal reaching a maximum of 243,926 pounds, valued at $373,652 in 1903 (fiscal year). After bismuth commenced to be recovered in the United States imports declined to 133,190 pounds valued at $241,448 in 1914 (fiscal year). As a result of the World War, imports were further reduced, reaching a minimum of 18,494 pounds valued at $39,653 in the calendar year 1924. For the five-year period, 1925-1929, the average imports amounted to 58,760 pounds annually, roughly 20 per cent of domestic consumption. A marked downward trend is shown in the last few years.

England has been the principal source of imports and Germany is the only other important country of origin. During the war years, however, a little bismuth metal was received from independent smelters in South America.

Bismuth metal imported for consumption into the United States, 1901 - 1930

Year	Pounds	Value	Year	Pounds	Value
1901	165,182	$239,061	1916	76,723	$195,975
1902	190,837	213,704	1917	69,250	142,300
1903	147,295	235,199	1918	135,700	277,273
1904	185,905	339,058	1919	57,607	55,179
1905	148,589	318,007	1920	72,771	161,877
1906	254,733	318,452	1921	94,085	114,891
1907	259,881	325,015	1922	121,505	239,777
1908	164,793	257,397	1923	62,640	146,178
1909	183,413	286,516	1924	18,494	39,653
1910	198,174	332,668	1925	99,694	187,340
1911	172,093	311,771	1926	67,505	173,285
1912	182,840	316,440	1927	47,732	100,773
1913	117,747	213,257	1928	41,383	77,444
1914	90,505	165,208	1929	37,480	58,853
1915	44,362	108,288	1930	24,405	20,088

Bismuth salts imported for consumption, 1922-1930[1]

Year	Pounds	Value	Year	Pounds	Value
1922[2]	9,392	$ 8,681	1927	10,560	$15,080
1923	11,731	13,717	1928	8,168	16,336
1924	10,066	12,533	1929	3,552	10,645
1925	16,083	18,958	1930	657	5,083
1926	12,864	18,864			

1/ Not separately classified prior to September, 1922.

2/ September 22, to December 31, only.

TARIFF DUTIES

After being on the free list since 1857, bismuth metal was made dutiable at 7½ per cent on the foreign market value under the tariff act of 1922. The same duty was continued in the act of 1930 (par. 377). On chemical compounds and salts and mixtures of bismuth, the duty under the 1930 act is 35 per cent ad valorem (par. 22), the same as in the former act.

EXPORTS

Exports of bismuth metal are not recorded. Normally they are small or nonexistent, as the domestic market has always been supplied at least in part by imports. Smelter residues and fume containing bismuth are sometimes purchased by New York dealers for export, chiefly to Germany.

THE INDUSTRY IN FOREIGN COUNTRIES

South America

Bolivia.- For more than half a century Bolivia has been the leading source of the world's bismuth. One mine alone could easily supply more than has ever been consumed in a single year. The ores include native bismuth and bismuthinite and their oxidation products (principally bismuth ocher) and are always associated with tin. The leading deposits are in the departments of Potosi and La Paz in the eastern branch of the Andes (Cordillera Real). According to Ahlfeld[14] the largest deposits occur west of Illampu where bismuthinite occurs in nests and intimately mixed with chalcopyrite, tungsten, iron sulphides, and a little cassiterite along with tourmaline and siderite in a tourmaline hornfels not far from the contact with quartz monzonite. At Carmen-Aurora at Huayni Potosi (north of La Paz) masses of native metal weighing up to 1½ tons have been obtained but this interesting deposit is reported as virtually worked out. Other occurrences in northern Bolivia are considered insignificant. In the central part of the country at Uncia-Llallagua bismuth is a by-product of tin mining, and the Patino interests have marketed a large quantity of bismuth from this source despite the

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[14] Ahlfeld, Friedrich, (Oruro) Boliviens Wismutbergbau: Metall u. Erz, vol. 15, No. 24, 1927, pp. 353-356.

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fact that the ore averages scarcely 1 per cent of that metal. The Compagnie Aramayo de Mines en Bolivie, the largest bismuth producer in the world, has drawn its supplies from the southern part of the country where bismuth occurs in isolated mountain stocks, notably at Tasna, Ubina, and Chorolgue. Still further to the south in the vicinity of Esmoraca a number of deposits are known and the Pueblo Viejo mine has been a fairly consistent producer.

At the Tasna mine there are several veins in shale traversed by dikes of igneous rocks. The ore is sorted by hand and ores containing over about 25 per cent of bismuth are exported. Lower-grade ore is smelted with coke, producing metal or "matte" containing from 80 to 90 per cent of bismuth and a few per cent of copper, which is shipped to England for refining. Smaller amounts of bismuth in ore, concentrates, or residues are shipped to England and also to Germany and Belgium; occasional small shipments have been made to the United States. Formerly it was customary to estimate the bismuth contents of bars, concentrates, residues, and ores at 80, 50, 30, and 20 per cent respectively, but in 1929 the official export statistics show 86.87, 49.79, 43.27, and 25.48 per cent under the respective categories.

Peru.- The San Gregorio mine in the Cerro de Pasco district is the principal source of the exports of Peruvian concentrates running around 20 per cent bismuth. In 1929, 31,123 kilograms of bismuth were exported in the form of a lead-bismuth alloy. The Cerro de Pasco Copper Co. is a large potential producer of the metal. Some 20,000 tons of fume containing 2 per cent of bismuth are said to have been accumulated, and current production of this fume, which also contains about 40 per cent lead, amounts to between 2,000 and 3,000 pounds daily.

Other South American Countries.[15]- A small amount of bismuth has been exported from Argentina, produced in the provinces of La Rioja and Sierra de San Luis. In Brazil native bismuth and bismuth ocher occur in the gold mines of Minas Geraes; in the State of Rio Grande do Sul; and at Brijöes and St. Antonio du Jesus in Bahia. In Chile, native bismuth and other bismuth minerals occur near Juan Godoy and San Antonio, Atacania, and in Venezuela near Tocuyo.

Foreign North America

Canada.- Bismuth is a minor constituent of ores produced in both eastern and western Canada, and small quantities of bismuth concentrates have been more or less regularly recovered by the Deloro Smelting and Refining Co. in treating the silver-cobalt-nickel ores from Ontario. These concentrates have been shipped to the United States. Late in 1928 a bismuth separation plant was brought into production by the Consolidated Mining and Smelting Co. at the smelter at Trail, B. C. Both the companies produced metallic bismuth in 1929 and the Deloro company also exported a silver-lead-bismuth bullion for further treatment in United States smelters. The total output of metallic bismuth and bismuth contained in exports amounted to 194,329 pounds valued at $220,335 in 1929 as against 14,002 pounds worth $5,067 in 1928.

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[15] Mellor, J. W., Work cited, pp. 590-1.

Mexico.- Bismuth minerals occur in several parts of Mexico - in the States of Guanajuato, Jalisco, Queretaro, Sinaloa, Sonora, and Zacatecas[16] - but have been worked chiefly in Sinaloa and Sonora.

Australasia

According to Mellor:[17]

> Native bismuth occurs in the Owen goldfield, New Zealand. In Australia, native bismuth and bismuth minerals occur with those of tin, tungsten, and molybdenum. In New South Wales, bismuth deposits occur in the districts of New England, Cobar, and Whipstick; in Queensland in the Eastern districts, particularly Cook and Burnett - and comprising the districts of Kennedy, and Port Curtis, Moreton, Burke, Darling Downs, Leichardt, and Wide Bay; in Victoria, bismuth and bismuth ores occur at Linton, and Maldon; in Tasmania, in the Middlesex district, and at Dundas, South Heemiskirk, Mount Ramsay, Mount Lyell, and King Island; in South Australia, there is an important deposit in the Onkaparinga Hundred; and in Western Australia, at Melville.

In New South Wales, bismuth ores are found in quartz pipes developed in siliceous granites near the contact with basic igneous or sedimentary rocks; they are usually associated with molybdenite and less commonly with tin or tungsten minerals. In Queensland the occurrences seem to be somewhat similar, but the bismuth typically accompanies wolframite; during the war, especially, fairly large quantities of tungsten-bismuth concentrates were produced and shipped without separating the bismuth. In 1930, Bismuth Products, Ltd., was formed to acquire the assets of Marven Mines, Ltd., at Torrington, N. S. W. This apparently represents a revival of the bismuth mining activities formerly conducted by Elliott Bros., Ltd. Over 5,000 tons of ore are estimated as being in sight in a vein 25 inches wide and averaging 0.845 per cent Bi and 1.470 per cent WO_3. A new plant is projected to handle 150 tons of this ore weekly, indicating an output of 10,000 or more pounds of metal annually.

Europe

England and Germany are dominant factors in the international trade in bismuth but at the present time this prominence is not so much due to control of mines as to market agreements and refining facilities. Two London firms - Johnson, Matthey & Co. and May & Baker - are the main figures in the world supply of metal and salts, respectively. Formerly small amounts of bismuth were produced in England from unimportant deposits in Cornwall and

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[16] Zabriskie, Luther K. Mexican Mines and Mining, Bull. Pan-Am. Union, vol. 50, 1920, p. 282.

[17] Mellor, J. W., Work cited, p. 591.

Cumberland and also from Alva, Stirlingshire. In Germany, the ores found in the Erzgeberge constituted the basis for the monopoly enjoyed for several decades by the Saxon producers, but the output of German bismuth ores in recent yearshas been quite small. The principal occurrence is apparently at Alfenberg, but bismuth minerals occur also at Schneeberg, Johangeorgenstadt, Schwarzenberg, Annaberg, and Zinnwald in Saxony and at Wittschen and Schutzbach near Nassau. The Saxony Color Works, at Oberschlema, near Freiberg, is the leading producing interest. Both in Germany and in Czechoslovakia (Joachimstal) the bismuth content of the ores is quite small and it is recovered as a by-product. A number of German works produce bismuth metal and salts from imported as well as domestic ores. One plant at Beuel, near Bonn, is reputed to produce about 3 tons of metal a month.

Spain is probably the leading European source of bismuth ore, from the Conguista district of Cordoba, at Azuel, the ores are said to contain 0.5 to 7.0 per cent bismuth, 2 to 3.1 per cent cobalt and nickel, and smaller amounts of lead and copper and a little native silver. Near Torrecampos, Cordoba, two bismuth mines have been worked for a considerable time; the ore which contains up to 25 per cent and occasionally 45 or 50 per cent bismuth occurs in veins on a contact of the granite with slate (Silurian). The two companies, operating the San Jaime and Angelica mines, have produced as much as 200 tons of ore a year, mainly sulphides with a little carbonate. Ore from the San Jaime mine has been smelted in Cordoba, and recently a plant was built at Pozo Blanco to treat the Angelica ore. The metal quota of the latter works is said to be 20 tons. Early in 1928 four new bismuth mines were registered in a new bismuth zone on the opposite side of the contact. Bismuth occurs in the Rio Tinto pyrite-copper ores but ordinarily has not been recovered.

Soviet trade agents have endeavored to interest foreign capital in a bismuth occurrence, 70 kilometers from Tschika, in the Scherlova Mountain district, in Russia. In France small deposits are reported at Meymac, Corrèze; Pay-les-Vignes; and at Framont, Vosges. Occurrences in Austria, Jugo-Slavia, Rumania, Switzerland, Norway, and Sweden are listed by Mellor[18] Hungary has been an occasional contributor of ore.

Asia

According to Mellor:[19]

> Bismuth ores occur in Lower Burma. Small quantities have been found in the Dutch East Indies - near Lake Toba; Banca; Western Borneo; and Western Celebes. In China, some bismuth ochre has been produced in the Kiangsi Province; but the districts of Wong Yuen, Yuigte, Pao Au, Shiang Shau, and Chin Chow

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[18] Mellor, J. W., Work cited, p. 590.
[19] Mellor, J. W., Work cited, p. 590.

have deposits of bismutite and bismuth ochre, which are worked from the surface, and furnish over 5 per cent of the world's production. In Japan, there are scattered occurrences of bismuth ore which may be associated with ores of tungsten and molybdenum, and with gold, silver, or copper. The chief occurrences are at Nishizawa in Shimotsuke; Nakanosawa in Yechigo; Ikuno in Tajima; Imooka, and Hade in Mimasaka; Tomikuni in Tamba; and Kamioka in Hida. In Korea, there are deposits in the Hwang Hai Province. In Siberia, bismuth ore occurs between Olovyana and Berezoff, and also in the Zabaykalye region.

In Southern China bismuth is produced in several localities and after being accumulated in warehouses in larger cities (e.g., Changsha, Swatow, and Canton) is shipped for export from Hong Kong. The principal mines are at Kityang, Yungyun, Yan Ping, Fungshun and Chungshan, all in Kwangtung Province, At Kityang a mine has been worked for bismuth as the main product by the Tong Wu Wolfram Mining Shares Co., Ltd., organized in February, 1925.[20] At the other localities mentioned, bismuth is merely a by-product of tungsten mining. The production in China is frequently in the neighborhood of 50 tons a year. Prices as indicated by the export declaration from Canton for recent years average 55 to 65 cents (gold) per pound of ore. In Japan bismuth is recovered from the flue dusts at the Ashio copper mine. These dusts are a source of arsenic and the residue is smelted in an electric furnace to a lead-tin-bismuth alloy which is subsequently separated by electrolysis.

Africa

Bismuth is said to be rather widely distributed in Northern Rhodesia, particularly along the Lueno Valley, Many of the gold ores contain bismuth which has not been saved. In the Transvaal also bismuth accompanies gold, in the Sabi and Lydenberg districts. Bismuth has been reported on claims of the New Pretoria Silver-Lead Co. in the Waterbarg district, about 40 miles from Warmbaths. So far as known, however, no systematic bismuth mining operations have been conducted in the Dark Continent, the occasional exports being the result chiefly of prospecting operations.

MARKET CONTROL

It is common knowledge that the production and sale of bismuth and also of its salts have been more or less continuously controlled by agreements among the relatively small number of foreign producers. Saxony originally enjoyed a monopoly, but later Johnson, Matthey & Co. of London became the dominant producer and prior to the beginning of the American industry dictated world prices through agreements with the Royal smelters at Freiberg and Oberschlema, in Saxony, and the Deutsche Gold und Silberscheideanstalt of Frankfurt. Under this arrangement the London firm reserved for itself the American, French, and British markets and allocated the remainder of the world to the German concerns. The effectiveness of this control came to a test in 1905 when an independent German firm, the Anhaltische Blei-und Silberwerke, commenced to make the metal, but as the price was dropped from 9s. ($2.19) to 5s. ($1.22) by the older firms, the newcomer was forced to retire after a year or two.

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[20] Hinke, F. W. (American Consul, Canton), Bismuth: Bureau of Mines file 3023, August 9, 1930, pp. 16-17.

The situation in the United States has been aptly described by Brush:[21]

> The bismuth market in the United States closely follows that of London, and in that respect is similar to the tin market, with the difference that the price of bismuth is established by one firm, whereas that of tin by general trading in the market. The British price is fixed by Johnson, Matthey & Co., of London; the American quotation is generally merely a translation of that price in dollars and cents, making allowance for foreign exchange, import costs, and, at times, duty. The reason for this is obvious - i.e., as the firm of Johnson, Matthey & Co. seems willing to supply trade requirements at its official price, and as a demand exists in the United States as a general rule for the entire production in the United States, it is manifestly impossible to get more than the London price and it would be just as manifestly poor business to take less than the London price.

The theory of maximum returns has generally dictated the price of bismuth. There has been no clear evidence that lower prices tend substantially to enlarge the demand and ordinary good business judgment has limited offerings to what the market could absorb readily. The Tasna mine alone could flood the market and by-product production in the United States and elsewhere could be greatly increased if this were desirable. The introduction of Cottrell treaters at El Paso, for example, and the increased capacity at electrolytic lead-refining plants has increased the potential supply. Much bismuth is still wasted up the stacks of smelting works, and at least one company sells lead containing as much as 0.5 per cent bismuth to customers that can use it, rather than put it through the electrolytic process. Despite these dissipations, however, bismuth has accumulated in residues at smelting works in various countries in large amounts for which no present use is being made.

The leaders of the metal convention are Johnson, Matthey & Co. of London, the Saxon Color Works, and The Compagnie Aramayo de Mines en Bolivie (headquarters in Geneva). The ring covering bismuth salts is said to include May & Baker of London and a German cartel comprising Gehe in Dresden, Von Heyden in Radbeuel, Marquart in Beuel, Marckt in Darmstadt, and Riedel & Schering in Berlin.

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[21] Brush, Hamilton M., The Marketing of Bismuth: Eng. and Min. Jour., vol. 115, Feb. 10, 1923, p. 272.

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The principal American producers of bismuth metal are the United States Smelting Refining & Mining Co. and the American Smelting & Refining Company and the leading consumers are pharmaceutical firms with headquarters in Philadelphia, Saint Louis, and New York, respectively.

MARKETS AND PRICES

Bismuth is sold in 25-pound bars, the wholesale lot being 500 pounds, which is generally shipped by express to consumers. Bismuth bars are packed in wooden boxes, protected with iron strapping, 150 pounds of bismuth to the box. Wooden wedges are placed between the bars to prevent injury to the soft, brittle metal. There are no standard specifications but the pharmaceutical and medicinal trade demands a purity of 99.9 per cent and absolute freedom from arsenic (Betendorf test). The following is a typical analysis:

	Per cent		Per cent
Silver	0.05	Iron	0.005
Lead	0.005	Zinc	0.01
Copper	0.007	Bismuth	99.923

For alloy purposes less rigid requirements would be permissible, but since most of the consumption is for chemical preparations it is not worth while to make two grades. The principal consumption of bismuth is around New York, Philadelphia, and St. Louis and strangely enough, there is a seasonal demand, 70 per cent of the country's requirements being purchased in spring and summer.[22]

As might be expected from the extent of commercial control exercised by the leading producers, the price of bismuth has generally remained unchanged except at infrequent intervals. The London quotations are, of course, the barometer of the world market. From the low levels reached in 1895 (3s.) the London price rose fairly steadily to 7s.6d. per pound, which was the price that prevailed for more than four years immediately preceding the outbreak of the World War. In 1904 there was a temporary advance to 10s., but as this encouraged the entry of a new German producer it was followed by the reaction to 5s. noted under the section of this paper entitled "Market control." The absence of German supplies during and for a time after the war resulted in a maximum price of 12s.6d., which continued until it was cut to the pre-war figure of 7s.6d. during the world-wide depression of 1921. In the following year it rose to 10s., where it remained until 1924 when overproduction resulted in rapid accumulation of stocks in Europe. Normal conditions were soon restored, but in 1930 another break in metal prices followed upon the disruption of the Salts Convention in the previous year and offerings from independent producers in Japan and Germany.

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[22] Brush, H. M., Work cited, p. 272.

Prices of bismuth in London, 1892-1930

Date effective	Shillings	Date effective	Shillings	Date effective	Shillings
Sept., 1892	7.5	March 7, 1905	9.0	Nov. 11, 1924	6.0
May 31, 1894	4.25	Dec., 1905	5.0	Dec. 23, 1924	5.0
Nov., 1894	3.75	July 5, 1907	6.5	March 2, 1925	7.5
July, 1895	3.5	May 31, 1910	7.5	July 1, 1925	10.0
Oct., 1895	3.0	Aug. 17, 1914	10.0	Dec. 1, 1925	12.5
Jan. 25, 1897	5.0	March 7, 1916	11.0	March 2, 1926	10.0
July 23, 1900	7.5	Jan. 28, 1918	12.5	April 1, 1927	8.0
March 14, 1901	6.0	Feb. 19, 1921	7.5	Feb. 3, 1928	9.0
July 25, 1901	5.0	Jan. 18, 1922	9.0	July 9, 1928	7.5
March 18, 1903	7.5	Sept. 19, 1922	10.0	March 22, 1930	5.0
Nov. 30, 1904	10.0	Aug. 18, 1924	7.5	May 28, 1930	4.0
				Nov. 19, 1930	5.0

Prices of bismuth, per pound, wholesale, pharmaceutical grade, New York and London, 1907-1930

(Data from various sources)

Year	New York	London[1]	Import valuations
1910	\$1.70 - \$2.15	\$1.58 - \$1.82	2/ \$1.58
1911	2.10 - 2.15	1.82	2/ 1.80
1912	1.80 - 2.25	1.83	2/ 1.83
1913	1.75 - 2.25	1.83	2/ 1.70
1914	2.75 - 3.00	2.25	2/ 1.81
1915	2.75 - 3.00 3/	2.43	2/ 2.12
1916	3.25 - 4.00	2.67	2/ 2.43
1917	3.35 - 3.50	2.62	2/ 2.22
1918	3.35 - 3.50	2.99	2.94
1919	2.65 - 3.50	2.74	0.96
1920	2.40 - 2.70	2.29	2.22
1921	1.50 - 2.40	1.56	1.22
1922	1.50 - 2.45	2.04	1.98
1923	2.45 - 2.55	2.29	2.33
1924	1.50 - 2.55	1.96	2.14
1925	1.30 - 2.70	1.98	1.88
1926	2.70 - 3.35	2.53	2.57
1927	1.85 - 2.75	2.07	2.11
1928	1.70 - 2.25	1.97	2.05
1929	1.70	1.82	1.57
1930	1.00 - 1.70	1.23	.82

1/ Computed average converted at average current exchange for year.

2/ Fiscal year periods ending June 30th.

3/ Except at end of year, when it rose to \$4.

The price of bismuth in New York was formerly merely the London price plus the cost of importation. Freight and incidental landing charges normally add only about 3 or 4 cents to the cost to which is added also the duty which, at 7½ per cent normally ranges around 10 or 15 cents. The same confidential discounts on specially large orders are allowed by importers and domestic sellers. The first marked departure from pairity between the New York and London prices occurred in June, 1927, when the domestic producers reduced their quotation to within 3 cents of the British price. Subsequently the margin has changed, but has continued to be less than the importation cost differential.

Bismuth ores have rarely been marketable in the United States, although at times certain mining companies have received payment for as much as 4 per cent bismuth in lead or copper ores, either directly or indirectly through a reduction in treatment charges. Provided the by-product production was insufficient to supply the domestic demand, ores containing as much as 3 per cent of bismuth would probably be considered as having some additional value, but under existing conditions it is customary to consider the bismuth as detracting from rather than increasing the value of lead as well as copper ores. In general bismuth ores to be considered salable should contain at least 10 per cent of metallic bismuth, and ores shipped from several countries contain 50 to 65 per cent of the metal. In Bolivia the dividing line is around 20 per cent; ores containing under 20 per cent are smelted locally. Among objectionable impurities which tend to reduce the value of bismuth ores may be mentioned iron, copper, arsenic, lead, and tellurium.

LIST OF BISMUTH METAL PRODUCERS AND DEALERS

American Smelting & Refining Co., 120 Broadway, New York, N. Y.
United States Smelting, Refining, & Mining Co., 1 State Street, Boston, Mass.
Belmont Smelting & Refining Works, Inc., 330 Belmont Ave., Brooklyn, N. Y.
L. A. Cohn & Bro., Inc., Chicago, Ill.
A. C. Daft, Oliver Bldg., Pittsburgh, Pa.
Pope Trading Co., New York, N. Y.
Josef Radnai, 36 Fulton Street, New York, N. Y.
The Ore & Chemical Corporation, 40 Rector St., New York, N. Y.
China Commercial Co., Ltd., 225 Fifth Ave., New York, N. Y.
J. A. Samuel & Co., 220 Broadway, New York, N. Y.

LIST OF POSSIBLE PRODUCERS OF BISMUTH ORE AND RESIDUES

F. G. Sherry, Ketchum, Idaho.
Walter Higham, 1427 Tremont St., Denver, Colo.
Philip S. Hoyt, Las Tablas, N. Mex.
Leach and Leach, Tyrone, N. Mex.
H. T. Phillips, P. O. Box 31, Baker, Idaho.
F. T. Clarke, Lowell, Wash.
Interstate Ore & Metal Corporation, 60 E. 42nd St., New York, N. Y.

LIST OF POSSIBLE BUYERS AND CONSUMERS

Merck & Co. Inc., Rahway, N. J.
Chas. Pfizer & Co., 81 Maiden Lane, New York, N. Y.
Mallinckrodt Chemical Works, St. Louis, Mo.
McKesson & Robbins, Inc., 79 Cliff St., New York, N. Y.
New York Quinine & Chemical Works, 99 North 11th St.,
  Brooklyn, N. Y.
J. T. Baker Chemical Co., Phillipsburg, N. J.
The Ore & Chemical Corporation, 40 Rector St.,
  New York, N. Y.
J. A. Samuel & Co., 220 Broadway, New York, N. Y.
Belmont Smelting & Refining Works, Inc., 316 Belmont Ave.,
  Brooklyn, New York.
C. B. Peters & Co., (E. R. Dick), 110 William Street,
  New York, N. Y.
Jungmann & Co., Inc., 3 Desbrosses St., New York, N. Y.
Varlacoid Chemical Co., 15 Moore St., New York, N. Y.
Josef Radnai, 36 Fulton St., New York, N. Y.
Federated Metals Corporation, Woolworth Bldg.,
  New York, N. Y.
William J. Auw, 1952 Galbreth Road, Pasadena, Calif.